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ABSTRACT

One in a series of core instructional materials for apprentices to use during the first or second years of apprentice-related subjects training, this booklet deals with basic physical science. The first section consists of an outline of the content and scope of the core materials as well as a self-assessment pretest. Covered in the four instructional chapters included in the booklet are the relationship among work, power, and energy; mechanical energy and mechanics; heat energy; and electrical energy. Each chapter contains an overview; an introduction and objectives; principles, examples, and applications; additional information; and self-test exercises. Appended to the booklet are answers to the self-assessment pretest, answers to the self-test exercises, a posttest, and answers to the posttest. (MN)

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BASIC PHYSICAL SCIENCE

Apprentice Related Training Module

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Table of Contents

Glossary

The words on this list are used in this booklet. Review the terms and learn the definitions. The meaning of the words in the text may not necessarily be the definition or form of the word with which you are familiar.

Words/Terms

1. *Abbreviate* To condense or shorten.
2. *Accelerate* To cause to move faster.
3. *Application* A particular use.
4. *Buoyant* The tendency or ability to keep afloat.
5. *Calculate* To reason and plan, often using mathematics to work out the answer.
6. *Conserve* To keep from loss or depletion.
7. *Contrive* To plan or improvise.
8. *Converse* Turned about so that the two parts are reversed.
9. *Convert* To change or transform from one form to another.
10. *Designate* To indicate, specify, name or appoint to a special duty.
11. *Displace* To remove physically out of position.
12. *Distinguish* To indicate the difference between objects.
13. *Equation* A mathematical statement, similar to an English sentence except that it uses numbers, by which a relationship is stated.
14. *Equivalence* Being equal in value, meaning or effect.
15. *Force* A push or pull that changes the speed and/or direction of an object.
16. *Formula* An exact method, form or recipe for doing something.
17. *Illustration* An example or comparison that offers explanation.
18. *Perpendicular* Being at right angles to the horizon; being vertical.
19. *Proportion* The relative magnitude or degree existing between parts of a whole.
20. *Stipulation* A set of exact terms, guarantee or promise.
21. *Systematize* To reduce to an orderly arrangement of parts.
22. *Thermal* Pertaining to, determined by or measured by heat.
23. *Velocity* The speed of movement over an amount of distance in a specific amount of time.

1. How To Use This Booklet

What Is this Series About?

Basic Physical Science is one of ten booklets written as core instructional materials for apprentices to use during the first or second years of apprenticeship related subjects training. Nine of the booklets are about critical subject areas for apprentices, as determined by a national group of experts on apprenticeship and training. The tenth booklet introduces the other booklets and explains how to use the materials in the instructional setting.

The materials are designed to be used with other related subjects instructional materials. They can be employed in one of two ways: (1) the materials can be used as the total instructional materials package for some trades, in subjects such as basic science, measurement, and working in organizations; or (2) they can be used as supplementary, introductory or practice materials in subjects such as basic mathematics, safety and an introduction to apprenticeship.

The booklets are written in a self-instructional, self-paced format. They can be used either in instructor supervised or independent study arrangements. *Each booklet and each chapter is written as a distinct unit and is addressed to a single major topic.* This means that you or your instructor can select individual booklets or chapters without necessarily using every booklet or every chapter within a booklet.

The booklets emphasize application of facts, concepts and skills. Material is presented by means of written information, visual illustration and applied example. The discussion for most major topics also includes an application section that requires you as a learner to demonstrate what you are learning. In addition, each chapter contains a section entitled Self-Test Exercises that contains questions, problems and exercises for you to work through as a final application of the knowledge or skill and to show that you have mastered the materials.

The titles of the booklets in the core materials are:

1. A Basic Core Curriculum
2. Introduction to Apprenticeship
3. Basic Mathematics
4. Basic Safety I
5. Basic Safety II
6. Basic Measurement
7. Sketching, Drawing and Blueprint Reading
8. Basic Physical Science
9. Working in Organizations
10. Interpersonal Skills and Communication

What Is This Booklet About?

Science is both a process and a product. It is an organized body of knowledge or information through which humanity seeks to: (1) establish general laws and principles that explain the relation of phenomena and (2) control the environment by applying established principles and laws to prob-

lems that occur in our daily lives. This booklet is concerned with the work applications of science for apprentices in their chosen occupations. The aim is to address both the theoretical and practical aspects of the information so as to ensure that the apprentice learns what and why something on the job occurs in a specific way. The information is limited only to those principles judged most critical to a large number of apprentices. The specific topics covered in this booklet are:

1. Work, Power and Energy
2. Mechanical Energy and Mechanics
3. Heat Energy
4. Electrical Energy

What Must I Do To Complete My Work In This Booklet?

Working your way through this booklet will require you to read the text, to answer the questions, to perform the exercises and to complete the pretest and posttest instruments. Expect to spend about five hours working through the materials. The only resources you need to complete your work in this booklet are: (1) a copy of the booklet; (2) a pencil or pen; (3) a ruler; and (4) about five hours of time.

The materials are written in a self-instructional, programmed format. You may work through the test, examples, and questions at your own pace and leisure. You need not complete your work in the booklet in one sitting.

Each chapter in the booklet is devoted to a single skill, competency or unit of knowledge. The general format of the chapters is similar, with the following parts:

1. A *chapter overview* containing all the necessary information you need to know in order to work through the chapter.
2. An *introduction* describing the knowledge or skill and the instructional objectives for the information.
3. *Principles, examples, and applications* presenting and explaining the content as well as offering you practice opportunities to apply the information.
4. Additional sources of *information*.
5. A *self-test exercise* for applying the information under consideration.

This booklet concludes with an Appendix that contains the answers to the pretest, the self-test exercises from each chapter and the posttest.

How Much Do I Know About The Subject As I Begin?

Begin your work in *Basic Physical Science* by completing the self-assessment pretest that follows. When you have completed the pretest as directed in the assessment instructions and have finished reading the other material in this introductory section, continue your work in this booklet, one chapter at a time. Begin with Chapter 2 unless the results of your self-assessment indicate that you should do otherwise.

In each chapter, do the following:

1. Read:
   - Background information.
   - Steps and procedures for performing skilled activities and explanations of major points and ideas.

- Examples illustrating use of information, performance or skill, or application of material.

2. Consider the questions and exercises in the text. Work the questions and check your answers.
3. When you believe that you have mastered the material, take the Self-Test at the end of the chapter.
4. Check your answers with those provided in the Appendix at the end of the booklet. If you achieve at least the minimum acceptable score, move to the next chapter. If your score is below acceptable levels, work through the chapter again.

Self-Assessment Pretest

Directions: The self-assessment will help you focus on specific strengths and limitations of your science knowledge and skills. Select the best answer for each question and record it in the appropriate space. After you have worked through the entire pretest, score your test following the directions at the bottom of the test.

1. How much work is involved in lifting a 20 lbs. weight vertically onto a platform that is 6 feet high? Answer: ____________________
2. Identify the product of force multiplied times distance. Answer: ____________________
3. If 47,000 foot pounds of work is done by a machine in a minute, what is the horsepower used by the machine? Answer: ____________________
4. If a four-wheeled wagon is loaded with a load that weighs 250 lbs. and you are pushing at a constant velocity of 50 feet a minute on a level surface, what force must you exert to keep the cart moving at this speed and in a straight line, discounting friction? Answer: ____________________
5. If an empty carriage, using hydraulic brakes takes 70 feet to stop when traveling at a maximum of 5 m.p.h., how much distance will be required to stop the carriage using the same brakes when the carriage is loaded, given that the loaded weight is three times that of the empty weight? Answer: ____________________
6. What three external forces must be worked against in order to change speed and direction of a body? Answer: ________________; ________________; and ________________.
7. What effect does a lever have upon force? Answer: ____________________
8. How much force must be applied to lift a load using a lever that has a force distance of 10 feet, a load distance of 2 feet and a load of 1000 pounds? Answer: ____________________
9. What is the pressure of the water in a square tank measuring 30 cm (length) × 20 cm (width) × 40 cm (height)? Answer: ____________________
10. What is the equivalent of mechanical energy for 1 Btu of heat? Answer: ____________________
11. What is the process of heat transfer involved in hot air and hot water heat? Answer: ____________________
12. Express 25°C in Fahrenheit terms. Answer: ____________________

13. If 7500 ft. lbs. of mechanical energy perform 7200 ft. lbs. of work plus some surplus heat, how much heat is produced? Answer: ____________

14. How many amperes are passed in a system that has 120 volts and a resistance of 3 ohms? Answer: ____________

15. How much power is produced in a situation in which there is 50 volts and 40 amperes? Answer: ____________

16. What are the two types of electricity? Answers: ____________ and ____________

17. What are the component parts that produce electricity in an electric motor? Answer: ____________ and ____________

18. If two charged objects repel each other, of what kind are their charges? Answer:

Scoring: Count the number of correct answers in each of the following three sets of questions. Use the information in the Chapter Overview for each chapter.

Questions 1–3 # correct ______
Questions 4–9 # correct ______
Questions 10–13 # correct ______
Questions 14–18 # correct ______

2. Work, Power And Energy

Chapter Overview

Purpose:	To introduce basic terms and background information associated with science applications in the workplace.
Preassessment Score:	Regardless of your pretest score, please work through this chapter.
Prerequisite:	Chapter 1 of this booklet Basic Mathematics module or its equivalent for working equations and solving for unknowns.
Resources:	Time—At least 30 minutes to complete Materials—Pencil
Performance Statement:	At the conclusion of this chapter you will recall and apply the major facts and principles associated with work, power and energy.
Performance Measure:	A fifteen-minute paper-and-pencil posttest to be taken after completing the entire booklet.
Standards:	To be successful, you must answer at least 70% of the posttest items correctly.
Activities:	1. Read text, samples, and illustrations and commit information to memory. 2. Work questions, examples and problems. 3. Complete and check the self-test exercises and posttest.

Introduction and Objectives

Energy and work are terms with everyday applications that are used frequently in ordinary language. For example, you probably have heard people say things such as "I simply don't have the energy 'to play' or '. . . to finish mowing the lawn' or ". . . to fix dinner' or ". . . to go to work today'." In making such statements, the speaker suggests an association between the terms work and energy. Most people realize that it take energy to work, to play, and sometimes to relax. Yet for most people the exact nature and definition of work and energy is unknown. In this chapter, you will learn about the concepts of work, energy, and power. When you have completed your work in this chapter, you will demonstrate your understanding by being able to:

1. Define and explain the concepts of work, energy and power; and
2. Calculate necessary work and power to perform certain jobs.

Principles, Examples and Applications

Work

How many meanings can you think of for the word "work"? Most apprentices would consider reading these materials to be work. Likewise, most trainees would consider operating a lathe, calculating the amount of concrete needed to pour a floor, or laying a subfloor to be work. Certainly these activities are "work." However, so too is an activity such as "playing" softball. In fact, in a technical sense, playing softball requires a great deal more work than reading these materials, as you will learn as you work through the following materials.

Work is the product of a force affecting a body of matter, multiplied by the distance through which the force operates. In addition, the force and the motion of the object across distance must be in the same direction. This means that if you were to lift a 60-pound bag of cement from the floor the the bed of a pick-up truck four feet off the ground, you would do a certain number of units of work. Likewise, playing softball involves doing units of work when you swing the bat through the distance necessary to hit the ball, throw the ball and run. In comparison, reading these materials involves almost no work other than turning pages and occasionally moving the pencil to work a problem; so far, it is not possible to measure mental effort.

The formula for calculating work is written as:

Work = force × distance or $W = fd$

Therefore, if you had lifted the 60-pound bag over a distance of four feet, you would have done 240 units of work. Notice that the formula neither includes anything about time nor says anything at all about the relative usefulness of the work done. All the formula does is allow you to compute the amount of force applied as a push or pull times the distance over which the force is applied. Force is measured as weight and can be anything that tends to speed up or slow down motion of an object or that changes it direction. The formulas apply to both vertical and horizontal situations as shown in Figure 1.

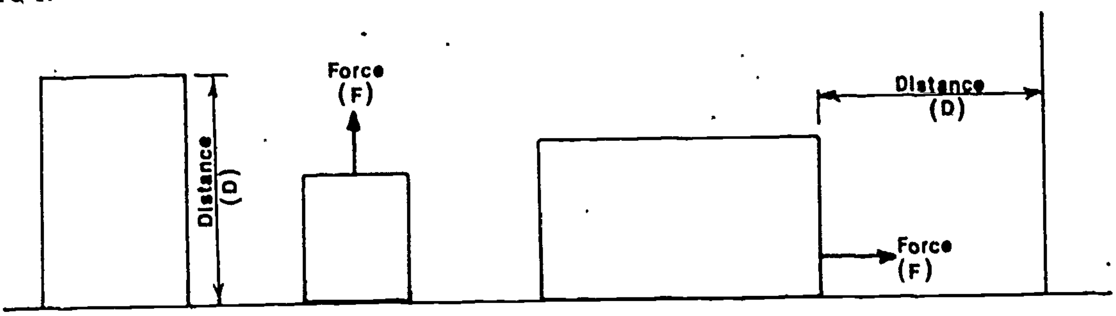


Figure 1: Work in Vertical and Horizontal Situations

As mentioned earlier, units of work are the product of the equation of work = force × distance. The expression for units of work arises from the formula. Since distance is usually measured in feet and force is usually measured in pounds of weight, the unit of work in the conventional measurement system is called a foot-pound. It is abbreviated as ft.-lb. A single foot-pound is the amount of work done by a force of one lb. acting through a distance of one ft., the force and distance being in the same direction.

In the metric system, the erg is the basic unit of work. It is the amount of work performed when a force of one dyne moves through a distance of one centimeter. Because they are so small, ergs usually are expressed in larger units called joules. One joule is equal to one million ergs and usually is written as 10^6 ergs.

The foot-pound is larger than the joule. One joule is equal to about .7 foot-pounds. In the United States, the preferred measure is foot-pounds. Use it for your calculations.

Solve the following problems using the formula for work. Express your answers in units of work so that the answer has meaning.

1. How much work is done in lifting a twelve-pound concrete block onto the top of a six-foot wall? Answer:
2. If 180 foot-pounds of work were performed in moving a 6-pound weight, how far was the weight moved? Answer:

Answers: 1. = 72 ft.-lbs.
2. = 30 feet

Power

The formula for computing amount of work done does not include a time consideration. This means that the *amount of work* done in moving two truckloads of lumber is the same whether it is done in two hours or eight hours. The concept of power introduces time into the equation. Power is the rate at which work is done. It is equal to work divided by time. In equation form, it is written in either of the following ways:

$$\text{Power (P)} = \frac{\text{Force (F)} \times \text{distance (d)}}{\text{time (t)}} \quad \text{or} \quad \text{Power (P)} = \frac{\text{Work (W)}}{\text{time (t)}}$$

For mechanical and heat energy, power is expressed in terms of horsepower. One horsepower is equal to a rate of 550 foot-pounds per second or 33,000 foot-pounds per minute. A machine that works at a rate of 55,000 ft.-lbs./sec. is designated as 100 horsepower.

Electrical power is measured in watts or kilowatts. A watt is the amount of power involved when work is done at a rate of one joule per second. One kilowatt is equal to 1,000 watts. It takes 746 watts of power to equal one horsepower.

Workplace examples of power and horsepower are numerous. Most vehicles and machines have a horsepower rating that indicates work capacity. Power and horsepower calculations are useful and uncomplicated as long as you perform each step in the process. Take as an example that you want to determine the horsepower of a freight elevator working at maximum load and speed. The fully loaded elevator weighs 10,000 lbs. The length of lift is 80 feet and the time required to lift the load to that height is 30 seconds. To solve for horsepower, you use the following steps:

First, calculate work done:

$$W = fd$$
$$W = 10{,}000 \times 80 \text{ feet}$$
$$W = 800{,}000 \text{ ft.-lbs.}$$

Second, calculate power rate:

$$P = \frac{W}{t}$$
$$P = \frac{800{,}000 \text{ ft.-lbs.}}{30 \text{ sec.}}$$
$$P = 26{,}666.67 \text{ ft.-lbs./sec.}$$

Third, solve for horsepower:

$$HP = \frac{\text{foot-lbs./sec.}}{550 \text{ ft.-lbs./sec.}}$$
$$HP = \frac{26{,}666.67}{550}$$
$$HP = 48.48$$

Solve the following problems, using appropriate formulas. Express your answers in appropriate units of measure.

1. An earth mover weighed ten tons when filled to capacity. Moving at its maximum steady rate, it carried a capacity load of earth and rock 3000 ft. in five minutes. How much work was done on each load and what was the horsepower rating of the machine? ______________
2. Two back hoes are available to move sand. One is rated at 80 horsepower and one at 75 horsepower. Given that 40 tons of sand must be loaded and moved the necessary 10 feet each hour, how much time per load could be saved by using the machine with the larger horsepower rating? ______________

Answers: 1. = 60,000,000 ft.-lbs. and 363.64 horsepower
2. = About 1.2 seconds per load, based on horsepower

Energy

Energy is the capacity to do work. It is defined in terms of what it can do because no one is exactly sure what energy is. By saying that energy is the capacity to do work, it is possible to describe and measure energy even without being able to explain exactly what it is.

Three kinds of energy with work applications are covered in this booklet: mechanical, heat (thermal) and electrical. Each type of energy is addressed in a separate chapter. However, before considering each type separately, study the following paragraph about energy conservation and transformation.

The principle of conservation of energy states that energy can neither be created nor destroyed; it only can be transformed from one form to another with exact equivalence. The total amount of energy does not change *even though the portion available to do certain types of work*, after being transformed from one form to another, given existing technologies, *may be decreased due to inefficiencies in the transformation and recovery process.* For example, in an operating gasoline-powered engine, fuel—a type of chemical energy—is burned, producing heat energy, which is converted to a type of mechanical energy that moves the car. Not all the heat energy that is converted is useable; some must be dissipated by circulating water and air through a cooling system. While the total amount of energy in the conversion from chemical to mechanical and heat energy was exactly the same, due to limiting technology only that portion converted to mechanical energy was useable in this particular example.

Additional Information

For additional information about work, power and energy, you might choose to read:

G. Holten and S. G. Bush. *Introduction to Concepts and Theories in Physical Science*. Reading, Mass.: Addison-Wesley Publishing Co., 1973.

V. H. Booth. *Elements of Physical Science*. Toronto, Canada: The MacMillan Co., 1970.

Self-Test Exercises

Answer the following questions in the space provided. Check your answers with those provided in the Appendix. If you score at least 70 percent correct answers, continue your work with the next chapter. If you score less than 70 percent, repeat your reading of this chapter.

1. If work is the product of a force acting and the distance through which it acts, what is the stipulation about the direction of the force and distance? Answer: ____________
2. How much work is done if you lift an object that weighs 120 lbs. through a vertical distance of 5 feet? Answer: ____________
3. Compute the work done by a 120 lb. man who must carry a loaded hod weighing 60 lbs. to a platform 10 feet above the ground, directly above the load on the ground. Also calculate his horsepower if he must take a load every 40 seconds. Answers: ____________ and ____________
4. How many watts are there in 1 horsepower? Answer: ____________
5. What horsepower would a machine have that works at a rate of 2200 ft.-lbs./sec.? Answer: ____________
6. State concisely the principle of conversion of energy. Answer: ____________

3. Mechanical Energy and Mechanics

Chapter Overview

Purpose:	To acquaint each apprentice with information about the form of energy most directly responsible for powering machinery.
Preassessment Score:	Write in the following space the number of correct answers from pretest questions 4–9 ________. If you answered at least five of the questions correctly, skip to Chapter 4. If you missed two or more questions, continue to work through this chapter.
Prerequisites:	Chapters 1 and 2 of this booklet Basic Mathematics module or its equivalent for learning to work with fractions and solve for unknowns
Resources:	Time—At least 90 minutes to complete Material—Two pencils of equal length, paper
Performance Statement:	At the conclusion of this chapter you will identify, discuss and apply the major concepts of mechanical energy and mechanics to work situations.
Performance Measure:	A fifteen-minute paper-and-pencil posttest to be taken after completing the entire module.
Standards:	To be successful, you must answer at least 70% of the posttest questions correctly.
Activities:	1. Read text, examples, and illustrations and commit information to memory. 2. Work questions, examples and problems. 3. Complete and check the self-test exercises and posttest.

Introduction and Objectives

Mechanical energy is discussed first among the forms of energy in this booklet because it is usually the final form energy takes in industrial applications and work settings. Mechanical energy is used to work against the forces of friction, gravity, and inertia. Usually the work employs simple machines like levers, inclined planes, or pulleys, or combinations of these machines. Fundamental concepts include motion, simple machines, and several important scientific laws and principles.

The principles of simple machines and mechanical energy are fundamental to our lives. They are involved in everyday activities like turning the pages of this booklet, reading, drinking a glass of water, opening a door, using a hammer, or operating a sophisticated piece of machinery. When you

have finished your work in this chapter, you will demonstrate your understanding of mechanics and mechanical energy by being able to:

1. Distinguish between and select among simple machines, as well as explain how they perform work;
2. Identify critical components of scientific laws and principles involved with mechanics and mechanical energy; and
3. Analyze work situations to identify applications of mechanics.

Principles, Examples and Applications

General Information

Mechanical energy is used to bring about desired changes in matter by working against the external forces of inertia, gravity, and friction. Mechanical energy applied against the force of inertia produces a change in the speed of the object to which the mechanical energy is applied. Mechanical energy working against the force of friction changes the location of the object. Mechanical energy working against the force of gravity changes the height or altitude of the object.

In each instance, the work performed through mechanical energy produces not only changes in the position of the object to which the mechanical energy was applied, but also changes in the energy of the object on which the work is performed. More specifically, work against friction produces heat energy; work against inertia produces kinetic energy; and work against gravity produces potential energy. Potential energy and kinetic energy are two kinds of mechanical energy.

Kinetic energy is energy due to motion. It is the primary type of energy involved in work done by a pile driver, a hammer, a wrecking ball, and other similar tools. It is sustained by inertia and in many situations is the mirror-image opposite of potential energy. Potential energy is energy due to the position of matter with regard to gravity. It is based on both the weight and the height of the matter containing the energy. It is converted from potential to kinetic energy when gravity is allowed to exert force on the body, causing the body to fall to earth. Therefore, the hammer of a pile driver held still at its full height has full potential energy, and zero kinetic energy. When the hammer is released toward earth, the potential energy is converted to kinetic energy; maximum kinetic energy and zero potential energy is achieved just before impact. Figure 2 illustrates the relationship between kinetic and potential energy.

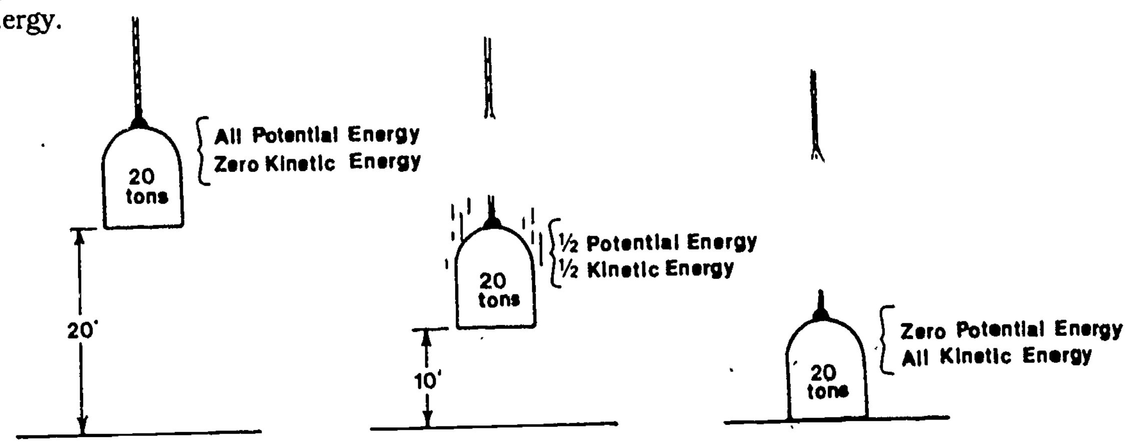


Figure 2: Kinetic and Potential Energy

Laws of Motion

The most critical concept for understanding mechanical energy and mechanics is motion. Sir Isaac Newton, a British physicist of the late 1600's, combined his personal observations with those of others to generate Newton's Laws of Motion. Stated briefly, they are:

Newton's First Law of Motion

Matter at rest tends to remain at rest and matter in motion tends to remain in uniform motion in a straight line until some external force acts upon the matter.

The first law of motion explains why, if you are standing on the sideboard of a truck that begins to move, you seem to fall toward the rear of the vehicle. Actually, the rear of the vehicle is moving toward and by you. Your own inertia tends to keep you still even though the truck begins to move.

The first law of motion also applies to objects in motion. Once an object is in motion, inertia resists attempts to change the speed and/or direction of the object. This principle applies when you shovel a spade full of sand into a concrete mixer. Your muscles exert mechanical energy to overcome inertia of matter at rest and start the shovel and sand moving. Your muscles stop the shovel, but the inertia of motion propels the sand on in the direction in which you started it until the forces of gravity and friction bring it to a stop.

Several important principles arise from Newton's First Law. Most notably: *A body of matter possesses inertia in direct proportion to its mass; the greater the mass, the greater the inertia.* Therefore, a great deal more force is required to start a car moving that is required to start a wheelbarrow moving, because the car weighs much more than the wheelbarrow. In like manner, a great deal more force is required to stop a car than is required to stop a wheelbarrow.

It is necessary to exert force to change the speed or the direction of an object. However, were it not for the external forces of friction and gravity, once a body was placed in motion from rest, it would not be necessary to exert any additional force in order to keep the object moving. Force only would be necessary to change the speed or direction of the object.

Newton's Second Law of Motion

A force applied to a body that is free to move will change the velocity of the body. Further, the force is equal to the mass of the body times the acceleration. This means that the acceleration of the body is directly proportional to the force applied; further, the acceleration occurs in the direction of a straight line in which the force is exerted.

This means that when a force such as gravity is exerted on a movable body such as the hammer of a pile driver, the object will move in a straight line in the direction of the exerted force unless it is restrained. Further, the acceleration of the hammer, unless restrained, will be proportional to the force exerted. Newton's Second Law helps to explain why it is noticeably easier to drive nails downward into flooring than to drive them perpendicular to the floor into studs. When you work at a right angle to gravity, your arm muscles must overcome the force of gravity in both the upswing and hammer stroke. When you work parallel to gravity, only on the upswing must you overcome gravitational force. The downstroke uses gravity to increase the force of the hammer before it hits the nail.

Newton's Third Law of Motion

The third law of motion states that forces come in pairs; for every action, there is an equal and opposite reaction.

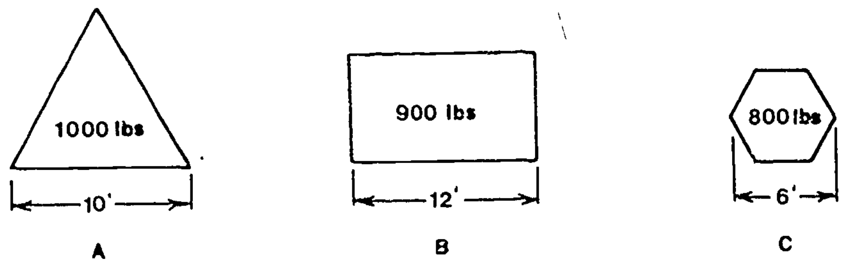
The third law explains why you may have slipped and fallen as you tried to push your car out of a snowdrift or a ditch. Inertia of the object at rest, the car, exerted a force on you equal to and opposite to your push on the car. This is the principle used to propel rockets and missiles. The fuel burn exerts pressure equally on all walls of the chamber; the opening in the rear of the chamber permits the hot, pressurized gas to escape backward with such a thrust that it pushes the projectile forward.

The most important work applications of the laws of motion are those related to safety. Remember, it takes much more energy to put an object at rest into motion than it takes to sustain motion.

More important, it takes much more energy to stop an object that is in motion than it takes to sustain the motion. The mass of an object and the speed of the object together determine how much force is required to start or stop motion. It takes twice as much force or twice as much distance to stop a loaded truck than an empty truck if the load doubles the empty weight of the truck. Consider the situation of a dump truck that weighs 15,000 pounds empty and stops in a distance of 100 ft. after traveling at 30 m.p.h. When the truck is loaded and weighs 30,000 lbs., at 30 m.p.h. it will take at least 200 ft. to stop. In addition, if the speed increases so does the braking distance and/or the force applied toward stopping. The principle of twice the distance or twice the force to stop or start, given twice the load, holds regardless of whether the load is the weight of buckets of sand, the speed of your lathe, or the load on the forklift.

Consider each of the following situations and suggest the best answer:

1. Which of the weights illustrated below will require the greatest force to start moving?



2. If an empty ore car moving at maximum speed takes 40 ft. to stop when the mechanical brake is applied full force, how far will it take to stop, using the mechanical brake, when the car is fully loaded, given that a fully loaded car weighs four times as much as an empty car?

Answers: 1. = A
2. = 160 feet

Simple Machines

The laws of motion are applied through simple machines. Simple machines are extensions of the body that assist the action of muscles. Even the most complex machines can be analyzed in terms of their component simple machines. Simple machines include levers, inclined planes, wheels and axles, and pulleys. Other machines such as the wedge and screw are variations of the basic simple machines.

Simple machines have the capacity to do work by changing force in one of three ways: (1) they can increase or multiply a force; (2) they can increase or multiply speed; and (3) they can change the direction of force. In each instance they facilitate motion. In all probability you have used several simple machines today before reading this material. Even the act of opening this booklet uses the principle of the lever with your arm, hand, and finger muscles.

The concept of mechanical advantage is imporant for working with simple machines. Mechanical advantage is the amount by which a given machine multiplies the force applied. It is calculated by dividing the load to be moved by the force to be applied. It is expressed as a ratio. While this calculation does not allow for friction—a force that will always reduce the advantage—it still is useful to you as you consider applications of simple machines to practical jobs. Specific comments on mechanical advantage are noted in the discussion of each type of simple machine.

The principle of conservation of energy is important when working with simple machines. Remember, you *never* get something for nothing, not even when using a simple machine. If you use a simple machine to lift or move a load by multiplying force, you also increase the distance over which you must exert the force.

Lever

Have you ever thought of a hammer, wheelbarrow or your own arm as a machine? They are; further, they are examples of the oldest and most useful machine, the lever. Formally defined as a rigid bar that is free to turn about a fixed point called a fulcrum, the lever multiplies force. Force is applied at one point on the lever in order to move a load located at another point on the lever. The fulcrum is the axis or leverge point of the lever. The distance between the force and the fulcrum is termed the force arm while the distance between the load and the fulcrum is termed the load arm. These distances and the weights involved are used to compute the amount of work that can be done with a lever.

There are three types or classes of lever that you can use to do work, as illustrated in Figure 3. The position of the load and fulcrum relative to the force determines the class into which the ~~lever falls~~. You can gain mechanical advantage from using any lever.

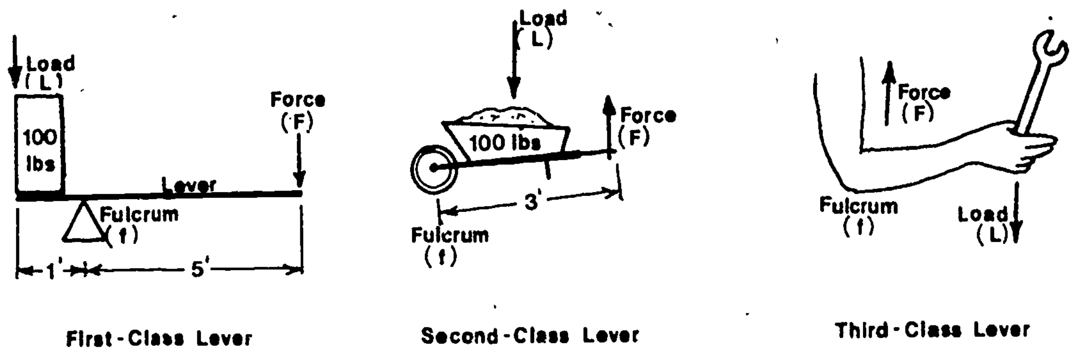


Figure 3: Different Types of Levers

The exact force or distance required to move a load with a lever is calculated by using the formula:

Force × Force Distance = Load × Load Distance

or

$F \times FD = L \times LD$

Using the formula, you can determine either the force you must exert to lift a load or the distance over which you must exert force. By combining this information with mechanical advantage information, you can determine the size, fulcrum position, and space needed to lift or move a load.

The amount by which a given machine multiplies force is called the mechanical advantage and is expressed as a ratio. You find the mechanical advantage for levers by dividing the length of the effort arm by the length of the load arm. The effort arm is the portion of the lever to which you apply force. The load arm is the portion of the lever on which the load rests. For example, for the first class lever illustrated in Figure 3, the effort arm is 5′ and the load arm is 1′. The mechanical advantage is five-to-one, written as 5:1.

Mechanical Advantage (MA) = Load (L)/Force (F) or Force Arm/Load Arm. These can be written as MA = L/F or MA = FA/LA. Study the following example of how to find mechanical advantage. The process and formula applies to virtually all simple machines.

Problem: What is the mechanical advantage of using a lever that has a load arm of 2 ft., a load of 500 lbs., a force of 100 lbs., and a force arm of 10 ft.?

Step 1: Set up equation in basic form.

MA = L/F

Step 2: Fill in known quantities and calculate MA.

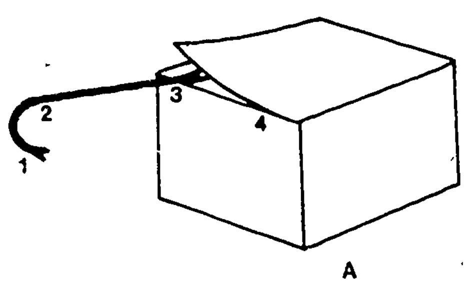
MA = 500/100 or mechanical advantage is 5:1

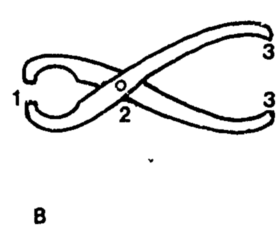
Work applications of levers are numerous and varied. Levers and lever principles are used as components in a variety of complex machines. Also, they are used in a number of ways as simple machines. For example, lever principles are used in operating a wood or a metal lathe. The tools used to take a cut are levers; the guard or rest is the fulcrum. Recall the safety rules for placing and holding the tool on the rest.

Other work applications for levers include the drill press and stamping machine. In each instance, the lever multiplies dramatically the force applied to the lever. Still other examples include the wheelbarrow, a pair of pliers or use of a hammer. In fact, most hand tools are simple machines like levers that dramatically increase force.

Answer each of the following questions about levers in the space provided.

1. Assume that an 800 lb. weight must be lifted by means of a lever, with a lifting force of 150 lbs. and load distance of 2 ft. How long must the force distance be in order to lift the load? Answer: ____________
2. Identify the fulcrum in each of the following pictures by circling the number that indicates fulcrum position.





3. What is the mechanical advantage of a lever that has a load arm of 2 ft. and a force arm of 12 ft.? Answer: ____________

Answers: 1. = At least 10.67 ft.
2. A = 3
2. B = 2
3. = 6:1

Inclined Plane

An inclined plane is a simple machine that permits a relatively heavy load to be lifted or moved while using relatively little force. Like the lever, the inclined plane multiplies force by helping to support some of the weight. An inclined plane is illustrated in Figure 4.

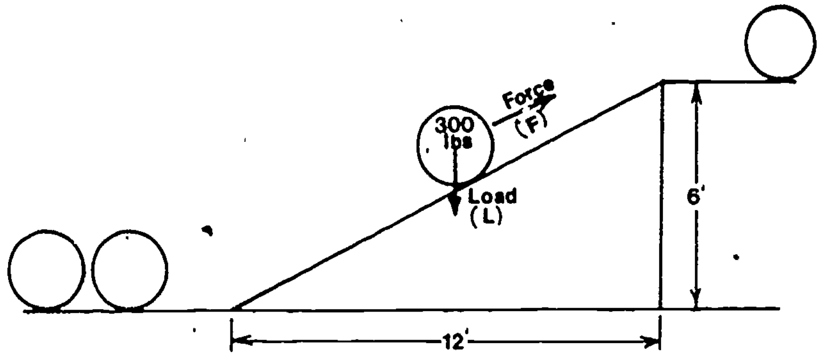


Figure 4: Inclined Plane

You find the mechanical advantage of an inclined plane by dividing the length of the base of the plane by the vertical rise of the plane. The advantage is expressed as a ratio. For the inclined plane in the illustration, the mechanical advantage is 2:1. You find it by dividing 12′ by 6′.

The exact force required to do the job with an inclined plane is found by using the formula: Force × Force Distance = Load × Load Distance. For the example in the illustration, the force required to do the job is 150 lbs. You find it by placing the values in the equation and solving as follows:

Force × Force distance = Load × Load distance
Force × 12 ft. = 300 lbs. × 6 ft.
$\text{Force} = \dfrac{300 \times 6}{12}$
Force = 150 lbs.

Remember, in calculating force and in using an inclined plane, a little extra force always will be required to overcome the force of friction.

You can find necessary force, load distance or the value of another unknown using the F × FD = L × LD formula. The formula holds for levers, inclined planes and pulleys. It is adapted slightly for wedges and screws. To calculate for any unknown, use the following process. In working the example, you determine the necessary force distance or the length of the inclined plane.

Problem: You must move a crate weighing 1000 lbs. from the ground onto a loading dock that is 6 ft. high. You can exert a maximum of 300 lbs. of force to move the crate. What is the necessary force distance or length of the inclined plane required to do the job?

Step 1: Set up the equation in basic form.
F × FD = L × LD

Step 2: Fill known quantities.
300 lbs. × FD = 1,000 lbs. × 6 ft.

Step 3: Perform multiplication on each side of the equal sign.
300FD = 6,000

Step 4: Divide to determine value of FD.
FD = 6,000/300
FD = 20 ft. (Force Distance or Length of Inclined Plane)

The same process can be used to determine the force, length of rope or space necessary to use a pulley and/or the force or length of clearance needed to use a lever.

On the job, a wood or metal screw is one of the most frequently used inclined planes. As a winding inclined plane, the point of the screw is pushed ahead with much greater force when turned in with a screwdriver (a type of lever) than would be the case if it were a nail and were merely driven in with a hammer. Likewise, two pieces of wood, fastened together with a screw are bound together much more strongly than would be the case if they were held together by a nail, because the screw multiplies the force that binds the wood together.

Other work applications of inclined planes include ramps, chisels, wedges, plows, scraper blades, nails and so forth. In each of these instances the inclined plane greatly multiplies the force and, in the case of the chisel, wedge and scraper, also changes the direction of the force.

Pulley

A pulley is a simple machine that consists of a wheel, usually with a grooved rim, around which a cable or rope can be wrapped. The pulley is important as a simple machine because it changes the direction of force. Further, it can be used in combinations of several pulleys (called block and tackles) not only to change the direction of force but also to multiply force.

There are three primary types of pulleys as illustrated in Figure 5. For the fixed pulley, the wheel is bolted to some stable object. The force required to lift the load is equal to the load. The merit lies in changing the direction of the force. Cranes work on this principle.

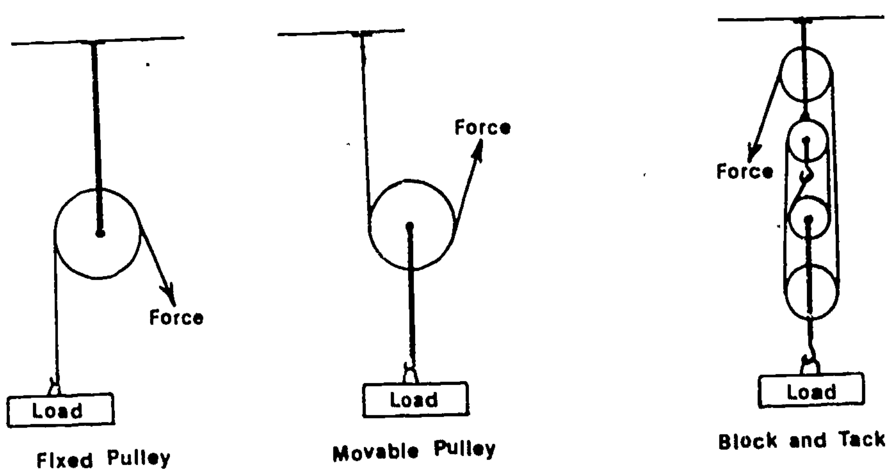


Figure 5: Pulley Types

In contrast to fixed pulleys, movable pulleys not only change the direction of force, but also multiply force. Part of the weight of the load is supported by the anchored cable or rope and the body to which it is anchored. You can lift twice the load with a movable pulley that you could have lifted with a fixed pulley given an equal amount of force. However, you will have pull the rope on a movable pulley twice the distance that would be necessary to pull the rope using a fixed pulley system.

Often, combinations of pulleys are used to move very heavy loads. The most frequently used combination is called a block and tackle. It is illustrated as the third type of pulley in Figure 5. Block and tackles not only change the direction of force, but also multiply force substantially. The number of ropes on the pulley wheels is the key. Each rope multiplies the mechanical advantage equally. If four ropes are attached to the block and tackle, it requires only one-fourth as much force to lift a one thousand pound load with the block and tackle as would be required to lift the same load with a fixed pulley. However, the distance you would have to pull the rope increases four times over that required for the fixed pulley. Again the equation of Force × Force Distance = Load × Load Distance applies:

$$F \times FD = L \times LD$$

The work applications of pulleys are numerous, especially in the construction industry. Take the hypothetical example of William Wilson, an apprentice stone mason. He is working on a monument. Wilson's job, among other things, required that he move the 1,000-pound granite blocks from a ground storage site up onto steel scaffolding being used by masons and sculptors. For the first few weeks, no crane or mechanical hoist was available. The scaffolding was bolted steel with corner poles that had been pile-driven to a depth of 6 feet. The scaffolding was 4 feet wide and formed a rectangle measuring 20 feet by 36 feet around the edge of the monument. The scaffolding was 20 feet high and had platforms every 5 feet up to the top.

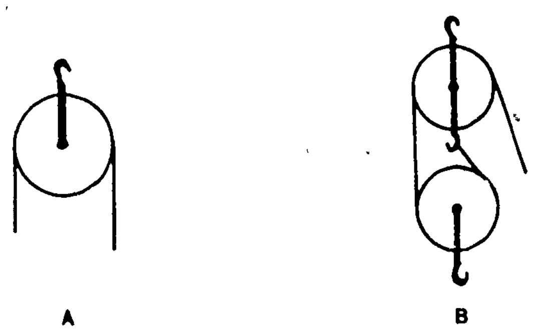
As Wilson surveyed his task, he considered each simple machine as a tool for moving the blocks. He calculated, for example, that without friction, he would need an inclined plane of about 80 feet in order to move a block to the top of the scaffolding. Even placing a block at the 10-foot level would require a ramp of about 40 feet, not allowing for friction. A lever was equally impractical, and he could not find a hydraulic jack with sufficient height or transportability to allow him to move blocks efficiently from one level to another.

Finally, Wilson considered using a pulley. He knew that he could fix one pulley on a corner pole, but could not exert 1,000 pounds of force without using a truck. He knew this meant too little control. The movable pulley was equally impractical; therefore, he chose to combine six pulleys into a block and tackle. He knew the mechanical advantage would be 6:1. Using unlimited amounts of rope and a chain harness, he would be able to hoist and control the granite blocks using about 160 pounds of force.

Answer the following questions about using pulleys.

1. When using pulleys, in order to lift a greater load with the same amount of effort, what do you need to do? Answer: ______________________________
2. What do the pulleys in each drawing do to force:

(insert figures here)



Answers: 1. Increase the number of ropes and wheels
2. A. Change direction of force
B. Change direction of force and multiply force

Wheel and Axle

The wheel and axle is a fourth type of simple machine. It not only multiplies force but also multiplies speed. A truck demonstrates wheels and axles performing both ways. For example, the steering wheel of a truck is a wheel and axle machine. It multiplies the driver's effort so much that with relatively little work a driver can turn a truck. The drive shaft, axle, and wheels of the truck offer a second example of a simple wheel and axle machine. In this instance it is not so much force as speed that is multiplied. When you consider distance, the wheel surface touching the road moves at great speed in relation to drive shaft speed.

Pressure

The discussion of motion and simple machines has focused on solids; liquids are governed by different principles and laws. Pressure and force are not the same thing. Force in liquid is determined by the weight of the liquid against the bottom of the container. It is calculated by determining the weight of the liquid using the formulas for volume that you mastered in your study of measurement.

Pressure is a different concept and calculation. It is equal to the force per unit area and is exerted equally in all directions rather than just as weight on the bottom of the container. The formula for calculating pressure, a skill fundamental to many occupations, is:

Pressure (P) = Force (F)/Area (A)

It is expressed as force per unit of area. Force simply means the weight of the liquid. Solving for pressure is performed by working the formula in two steps.

Problem: What is the water pressure of a square cooling tank that measures 6 ft. (180 cm) × 15 ft. (450 cm) × 3 ft. (90 cm)?

Step 1: Set up equation in basic form.

P = F/A

Step 2: Compute force by calculating the weight of water, using volume.

Length × Width × Depth

450 cm × 180 cm × 90 cm or 7,290,000 cubic centimeters, which equals 7,290,000 grams in the case of water.

Step 3: Compute area of bottom of tank.

Length × Width

450 cm × 180 cm = 81,000 square cm.

Step 4: Solve for unknown by division.

$$P = \frac{7{,}290{,}000}{81{,}000}$$

P = 90 grams per square centimeter

Pascal's Principle

Pascal's Principle states that whenever the pressure in a confined liquid is increased or diminished at any point, the change is transmitted equally throughout the entire liquid.

Hydraulic systems of all types are applications of Pascal's Principle. You can explain how a small force in a hydraulic press is multiplied several times. Figure 6 illustrates the principle.

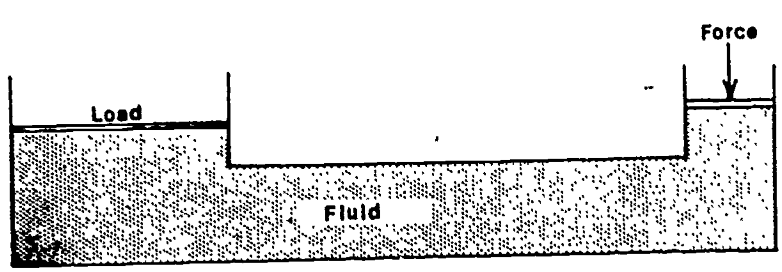


Figure 6: Pascal's Principle

The formula, equating the ratio of the forces on the pistons to the ratio of the areas of the pistons, is used to calculate for any unknown in dealing with pressure:

$$\frac{\text{Force (Large)}}{\text{Force (Small)}} = \frac{\text{Area (Large)}}{\text{Area (Small)}}$$

As with simple machines, the multiplication of force comes at the expense of increased required distance to be traveled in applying the force.

Consider the following question regarding Pascal's Principle and supply the correct answer:

In a hydraulic system, a weight of 4 tons was lifted on a platform that measured 100 sq. ft. The force of the lifter was applied to a surface that measured 4 sq. ft. What was the force applied? Answer: ____________

Answer: 320 lbs.

Archimedes' Principle

The buoyant force on a floating or submerged object is equal to the weight of the fluid displaced.

Archimedes is credited with observing and systematizing another critical concept related to the behavior of liquids. He found that the buoyant force on a floating or submerged object is equal to the weight of the fluid displaced. A floating body displaces its own weight, while a sinking body displaces its own volume. A 200-pound log floating in a river displaces exactly 200 pounds of water. If you were to stand on it and make it sink, your weight would have caused the log to weigh more than the volume of water that was displaced.

Bernouli's Principle

Bernouli's Principle states that where velocity of a stream of gas or liquid is increased, the pressure is decreased; the reverse is also true.

The Bernouli effect as illustrated in Figure 7 is used to give airplanes a lift. It states that pressure will be least where velocity is greatest. Airplane wings are shaped so that most of the air hitting the front wing is forced upward and over the top of the wing. This results in greater velocity of air above the wing and hence less pressure. Velocity below the wing is equal to that of the plane and considerably less than that on top. This results in a substantial upward pressure on the wing.

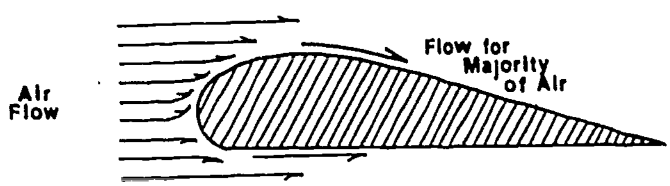


Figure 7: Bernouli's Principle

Gases

Gases behave somewhat differently than do either solids or liquids. Further, all gases are similar in regard to response to changes in temperature and pressure. Several important laws provide a foundation for working with gases.

Boyles' Law

Boyles' Law states that if the temperature remains constant, the volume of gas varies inversely to the pressure to which it is subjected.

This means that if the pressure on a gas is doubled, the volume of the gas will reduced by half; conversely, if the pressure if halved, the volume of the gas will expand to a volume double the original volume.

Charles' Law

Charles' Law states that when a gas under constant pressure is heated (or cooled) 1°C, it expands (or contracts) 1/273 of its volume.

Taken together, Boyles' and Charles' laws permit one to calculate the new volume of a gas where there is both a temperature and a pressure change.

Additional Information

For additional information on mechanical energy and mechanics, you might wish to read appropriate chapters from:

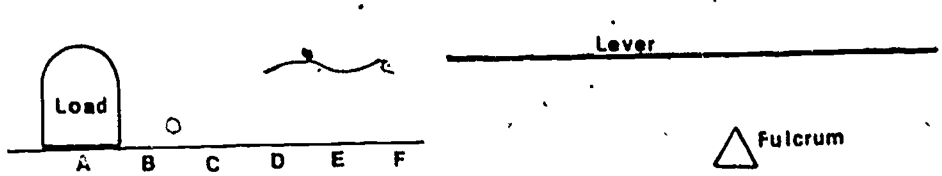
G. Holten and S.G. Bush. *Introduction to Concepts and Theories in Physical Science*. Reading, Mass.: Addison-Wesley Publishing Co., 1973.

V.H. Booth. *Elements of Physical Science*. Toronto, Canada: The MacMillan Co., 1970.

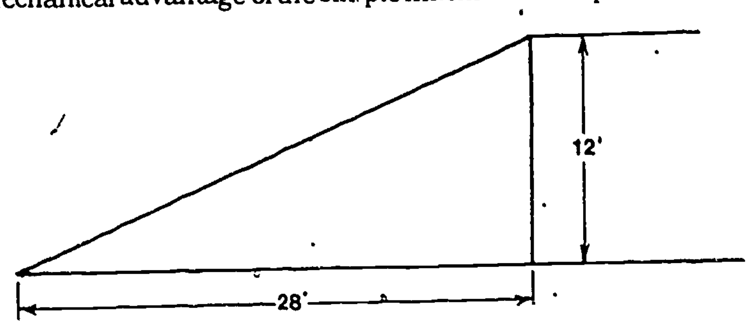
Self-Test Exercises

Answer the following problems and questions and compare your answers with those in the Appendix. If you answer 70% of the items correctly, go on to the next chapter. If you score less than 70%, repeat your work in this chapter.

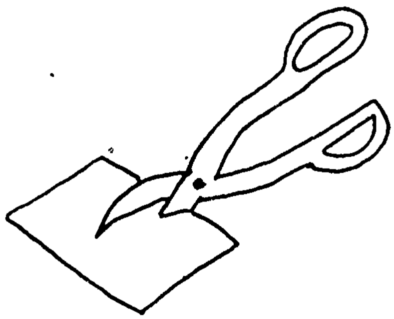
1. Where should the fulcrum be placed for use in lifting the load in the picture? Circle the number of the best fulcrum position.

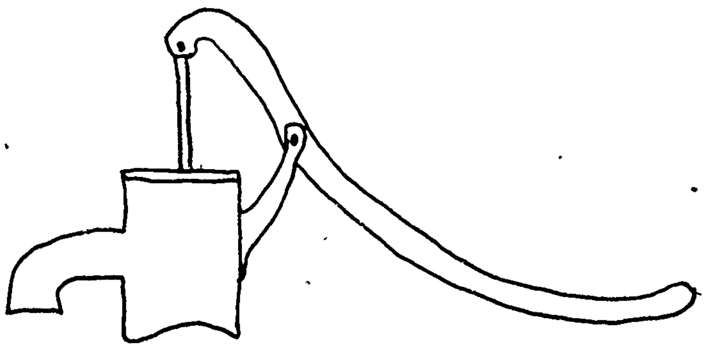


2. What is the mechanical advantage of the simple machine in this picture? Answer: ______



3. What amount of effort is required to lift a 600 lb. weight with a four-rope, movable pulley block? Answer: ______________
4. In what three ways do simple machines change force?
____
____
____
5. For each picture, mark the load with an "A," the fulcrum with a "B," and the best point to apply effort with a "C."





6. How much weight can be lifted on a hydraulic lift that has a platform area of 100 sq. ft., a force area of 10 sq. ft. and using a force of 200 lbs.? Answer: ______________
7. What conditions must be met to enable a concrete sailboat to float? Answer: ______________
____

4. Heat Energy

Chapter Overview

Purpose:	To acquaint apprentices with the principles, applications, and calculations related to heat energy.
Preassessment Score:	Write in the following space the number of correct answers from pretest questions 10–13 ________. If you answered all four correctly, skip to Chapter 5. If you missed a question, continue your work in this chapter.
Prerequisites:	Chapter 1 of this booklet Basic Mathematics module or its equivalent for solving for unknowns
Resources:	Time—At least 45 minutes to complete Material—Pencil
Performance Statement:	At the conclusion of this chapter you will identify, discuss and apply the major concepts of heat energy in work situations.
Performance Measure:	A fifteen-minute paper-and-pencil posttest to be taken after completing the entire booklet.
Standards:	To be successful, you must answer at least 70% of the posttest items correctly.
Activities:	1. Read text, examples, and illustrations and commit information to memory. 2. Work questions, examples and problems. 3. Complete and check the self-test exercises and posttest.

Introduction and Objectives

Heat as an energy force is familiar to everyone. The sun's warming rays, the warmth that results from friction as two objects are rubbed together, and the product of combustion—each is a form of heat energy.

Like other forms of energy, heat energy can be measured and used. In fact, while modern industry uses all types of energy, heat energy has remained the most widely used form of energy generated and converted to mechanical energy since the time of the Industrial Revolution. Not only are steam engines and turbines used to drive machines, but also heat is involved in some fashion in every conversion of energy from one form to another.

When you have completed your work in this unit, you will demonstrate your understanding of the principles and concepts related to energy by being able to:

1. Cite and explain work applications of this form of energy.

2. Convert temperature readings to and from Celsius and Fahrenheit scales.
3. Define key elements used in the measurement and harnessing of heat energy.
4. Recognize the laws of thermodynamics.

Principles, Examples and Applications

Introduction

Heat and temperature are different concepts. Heat refers to a form of energy; it means the *quantity* of energy contained by a body that can be used to do work. Temperature also is a quantity, but it is a measure, in degrees, of the *intensity* of heat. To illustrate the difference between heat and temperature, imagine the potential usefulness of the heat energy in two banks of water tanks in identical solariums of new office buildings. In one building, twenty 55-gallon black drums are allowed to heat unassisted in direct sunlight on a typical winter day. The mean temperature of the drums at the end of the day was 72°F. In the second building, the interior designer objected to the drums and persuaded the building owners to remove half of them. The remaining ten drums were placed in partial shade close to a gas-run fireplace. By the end of the same typical winter day, the temperature in the second set of drums also was 72°F. Therefore, the temperature in both sets of drums was equal. However, the twenty drums in the first solarium contained a great deal more heat—more potential to do work—than did the ten drums in the second solarium, because a much larger volume of heated material was available to do work.

Heat Units of Measure

Heat is measured in one of two ways: (1) the calorie or (2) the British thermal unit (Btu). A calorie is the amount of heat required to raise the temperature of 1 gram of water 1 degree Celsius. Since this is an extremely small unit, it is customery to express heat energy values in larger units called kilograms. One kilogram equals one thousand grams. When expressed as the fuel value of a food, 1000 grams often is expressed as 1 Calorie.

A Btu is a second way to express quantity of heat. It is the amount of heat required to raise one pound of water one degree Fahrenheit. The Btu is used in most industrial and engineering situations in the United States. One Btu is equal to 252 calories.

The unit of heat measure is important for two purposes. First, remember that different materials require different amounts of heat energy, expressed as calories or as Btu's, in order to change temperature. For example, one calorie is the amount of heat energy required to raise one gram of water one degree centigrade. However, only 0.11 calories of heat energy are required to raise the temperature of one gram of iron one degree centigrade. This phenomenon is called specific heat. It is the number of calories that are required to raise or lower the temperature of one gram of a substance by one degree centigrade. Each substance requires a different amount of heat energy to gain or lose temperature. For example, copper and aluminum have relatively low specific heat at 0.09 and 0.22 respetively, while water has a specific heat of 1.0. This means that one pound of water contains five times as much heat as one pound of aluminum if both are at the same temperature.

Units of measure for heat also are used to calculate the mechanical equivalent of heat in determining energy requirements. One calorie of heat is produced for every 4.18 joules of mechanical energy expanded, and one Btu of heat energy is equal to 778 foot-pounds of work. These values permit you to calculate work potential and horsepower ratings for heat energy machines.

Heat Transmission and Transfer

Do you know why fiberglass insulation helps to hold heat in your house or why your hands get cold when you touch a cold object? It has to do with heat transfer. Heat can be transmitted from one place to another in three ways. conduction, convection, and radiation. Conduction occurs when heat is passed from one molecule to another as the molecules vibrate and collide. Metals, particularly silver and copper, are excellent conductors. Conduction also can take place in liquids and gases as well as other solids.

During conduction, the transfer of heat is away from the body of matter having the higher tem-perature to the body of matter having the lower temperature.

Convection is the method of transferring heat through currents in the air or in liquids. It is the principle used in homes that utilize hot water heat. In such situations, the air in contact with a radiator is dried, warmed and driven upward by cool, heavier air. As the cooler air is dried and heated, it too is driven upward. Meanwhile, the warm air cools, is displaced by warmer, drier air, and moves to a lower position in the room. This pattern of air movement results in the house being heated. The use of mechanical blowers on wood stoves helps to create the same effect in a more efficient manner.

Radiation, the third method of heat transfer, requires no medium to transfer heat. Instead, heat passes through space at the speed of light. This is the type of energy provided by the sun. It travels in the form of electromagnetic waves. It also is the type of heat generated in microwave technology.

Two rules govern the process of heat transfer. First, when heat transfer is uninterrupted and unaided, it always proceeds from a warmer body to a cooler body. Second, while insulating a body to prevent heat loss or gain can slow the transfer process, it cannot entirely prevent the transfer. To date, there are no exceptions to either rule. Usually in industrial settings, however, simply retarding heat loss or gain through insulation is sufficient. Insulating materials impede convection and radiation flows. Good insulating materials include glass, fiberglass, and air. Fiberglass insulation in an attic is a good example of how insulation works. The foil backing retards radiation heat through reflection. The fiberglass itself fills air space with both air pockets and fiberglass. In doing so, it prevents convection by eliminating the avenues of air currents.

Consider the diagram of a thermos like the one that may be used on your job. It insulates by means of a sealed air space and fiberglass. Can you think of other applications of insulation and/or heat transfer on your job?

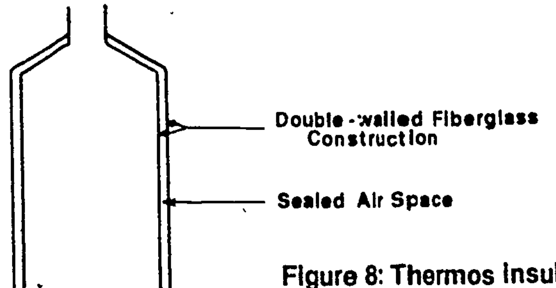


Figure 8: Thermos Insulation

Expansion and Contraction

Have you ever seen a concrete slab patio crumble due to the weather? If so, did you know it was due to the concrete expanding and contracting in weather extremes? Most materials expand when heated and contract when cooled. This principle makes it necessary to allow for small gaps between steel girders and rails as well as small gap joints between concrete blocks in roadways. Without room for expansion and contraction, many structures would buckle and crumble within several years of extreme weather. Even water expands and contracts in this way, for the most part. The exception occurs when water is frozen. Then it again expands as it becomes ice. The expansive force of a closed container of water often is sufficient to crack the container, even if the container is metal, such as the cylinder head of a truck engine.

Not only do materials expand and contract with changes in temperature, the expansion and contraction of different substances occurs at different temperatures. So, for example, brass expands and contracts much more quickly and with less expenditure of energy than does steel.

Temperature

Temperature is a word used in everyday conversation. The weather forecaster reports that the temperature will exceed 100°F or a neighbor says it is "hot" outside. Most people say they like their coffee steaming and their drinks ice-cold. Technically, the temperature of a body is determined by how fast the molecules within the body are moving; the more rapid the rate of movement, the higher the temperature. Temperature is a measure that is expressed as being relative to some other temperature.

In order to measure temperature, a thermometer is used. It is an instrument on which temperature is registered on a scale. The two primary scales are centigrade (or Celsius) and Fahrenheit. On the centigrade or Celsius scale, water boils at 100 degrees and freezes at 0 degrees, while on the Fahrenheit scale it boils at 212 degrees and freezes at 32 degrees. This means that there are 180 divisions between the freezing and boiling points of water on the Fahrenheit scale, as opposed to 100 divisions on the centigrade (Celsius) scale. One Celsius or centigrade divison, therefore, is worth 9/5 Fahrenheit divisions. This means that to convert temperature from one scale to another, the following formulas are used:

Centigrade (Celsius) temperature (C) = 5/9 times the difference between Fahrenheit temperature (F) and 32

$$C = 5/9(F - 32)$$

Fahrenheit temperature (F) = 9/5 times Centigrade (Celsius) temperature (C) plus 32

$$F = (9/5C) + 32$$

Take the example of a current temperature sign that registers 57°F. As an example of conversion, if you wished to determine the temperature on the Celsius or centigrade scale, you would perform the following steps:

First, select and set up the appropriate equation.

$$C = 5/9(F - 32)$$
$$C = 5/9(57 - 32)$$

Second, work the math to solve the problem.

$$C = 5/9(25)$$
$$C = 13.9°$$

Work the following problems for practice:

1. Express 83°F on the centigrade or Celsius scale
2. Express 30°C on the Fahrenheit scale

Answers: 1. = 28.3°C
2. = 86°F

Laws of Thermodynamics

Recall that energy can be neither created nor destroyed. The first law of thermodynamics extends this idea. When any form of energy is changed into another form of energy and then back to its original form, the original amount of energy is always produced even though some of it may not be useable. This unuseable energy often is heat. This means that it is impossible to build a machine that does work without energy from an external source.

The second law of thermodynamics states that it is impossible for a machine to cause heat to flow from a cooler to a warmer body without the aid of an external energy source.

Consider each of the following situations and indicate, based upon application of the laws of thermodynamics, what the correct answer is:

1. If 10,000 ft.-lbs. of mechanical energy is driving a machine that performs 9,000 ft.-lbs. of work and produces heat, how much heat is produced? Answer: ________________
2. Does a heat engine operate more efficiently at 25°F, 40°F, or 75°F?

Answers: 1. = 1,000 ft.-lbs. of heat
2. = 75° unless adjusted otherwise

Additional Information

For additional information about heat energy, you may choose to read:
V.H. Booth. *Elements of Physical Science.* Toronto, Canada: The MacMillan Co., 1970.

Self-Test Exercises

Answer the following questions and problems and compare your answers with those in the Appendix. If you answer at least 70% of the items correctly, go on to the next chapter. If you score less than 70%, repeat your work in this chapter.

1. Circle the letter of the statement below that is *not* a characteristic of temperature.
   a. Identical to heat
   b. The measure of heat intensity
   c. A quantity
   d. Measured on one of several scales
2. What is the freezing point of water on the centigrade scale? Answer: ________________
3. Circle the number corresponding to the number of foot-pounds of work 1 Btu equals.
   a. 447
   b. 554
   c. 668
   d. 778
4. Express 65°F on the centigrade or Celsius scale. Answer: ________________
5. Electrical energy is generated in a coal burning power plant such that a single generator burning 100 lbs. of coal produces 50 Btu's of heat energy, which converts to watts of electrical energy. What happened to the remaining heat energy? Answer: ________________
6. If the specific heat of water is 1.0 and the specific heat of copper is .09, approximately how much copper is required to equal the heat of one pound of water if both are heated to the same temperature? Answer: ________________
7. What is the process through which heat is passed from one molecule to another as they collide? It is the type of transfer most prevalent in metals. Answer: ________________

5. Electrical Energy

Chapter Overview

Purpose:	To acquaint each apprentice with the form and principles of electrical energy.
Preassessment Score:	Write in the following space the number of correct answers from pretest questions 13–18 ________. If you answered at least five of the questions correctly, skip to the posttest. If you missed two or more questions, continue to work through this chapter.
Prerequisites:	Chapter 1 of this booklet Basic Mathematics module or its equivalent in solving for unknowns.
Resources:	Time—At least 45 minutes to complete Material—Pencil
Performance Statement:	At the conclusion of this chapter you will identify, discuss and apply the major concepts of electrical energy to work situations.
Performance Measure:	A fifteen-minute paper-and-pencil posttest to be taken after completing the entire booklet.
Standard:	To be successful, you must answer at least 70% of the posttest questions correctly.
Activities:	1. Read text, examples and illustrations and commit information to memory. 2. Work questions, examples, and problems. 3. Complete and check the self-test exercises and posttest.

Introduction and Objectives

Even though the phenomenon of electrical charges was observed hundreds of years ago and has been studied ever since, there is still much to learn about electricity. Today we know, for example, that electricity is kinetic, molecular energy that involves the electrons of atoms, in both static and current forms. However, we do not yet know how to harness and store static electricity nor have we exhausted the ways of generating current electricity. Nevertheless, what is known about electricity is important to virtually every trade and craft, both because electricity is a common type of energy available for work and because safety practices in dealing with electricity are of critical importance. When you have completed your work in this chapter, you will demonstrate your skills and knowledge by being able to:

1. Explain the differences between static and current electricity;

2. Solve for unknowns to demonstrate the major laws and applications related to use of electricity on the job; and
3. Analyze situations to distinguish the relative effectiveness of conductors and insulators.

Principles, Examples and Applications

Static Electricity

There are two electrical charges—positive and negative. You can demonstrate the charges by scuffing your feet across a wool rug while wearing leather shoes, particularly in cool weather. After scuffing your feet, touch another person or a metal object. You will notice a shock or tingling sensation at the point of contact as well as observe a spark and hear a crackling noise.

The event you observe is the discharge of electricity. By scuffing your feet, you acquire a negative electrical charge. As you touch another object, an electrical charge is conducted from your person to the object you touch. The spark you see is the visual artifact of moving electrons just as lightning is on a much larger scale.

Negative charges are carried by electrons, the tiny particles that spin around the nucleus of atoms much as the planets spin around the sun. An atom is composed of negative charges carried by electrons that orbit the nucleus and positive charges carried by protons that are located in the nucleus or center of the atoms. As you scuff across the wool rug, you "rub-off" or borrow some of the electrons from the wool. They stay on your body surface until you touch a conductor that is positively charged and attracts them away. One basic premise of working with electricity is that like charges repel each other while unlike charges attract each other. This is one of the underlying notions of Coulomb's Law.

Coulomb's Law

Two unlike charges attract each other while two like charges repel each other. In each instance, the attraction or repulsion occurs with a force that is directly proportional to the square of the distance between the charges and is affected by placing a shielding medium between the charges.

The important points in Coulomb's Law to remember are:

1. Unlike charges attract each other while like charges repel.
2. The strength of the attraction or repulsion is as strong as the product of the charges.
3. As the distance between the charges increases, the attraction or repulsion changes at a much greater rate than the amount of distance.
4. Any shielding medium placed between the charges reduces the force of attraction or repulsion somewhat.

As suggested by the example of scuffing your feet on a wool rug, static electricity is usually generated by the friction of rubbing two objects together. Lightning is the best known example of static electricity. It too owes its charge to friction, the friction developed between the condensing water droplets falling through the cloud and the upward pushing air currents. While the exact process is not yet understood, it results in the falling raindrops having a positive charge and the upper clouds having a negative charge. The result is a flash of light signaling attraction between two massive unlike charges. The charges can be located in different clouds, or in different parts of the same cloud, or between clouds and earth. If the cloud is negatively charged and the ground positively charged, lightning will flash from the cloud to the earth. If the cloud is positively charged and the ground is negatively charged, lightning will flash from the ground to the cloud. Many times the upper cloud with the negative charge will be blown away, leaving a strong positive charge in a low cloud. This charge then induces a strong negative charge on the ground that results in lightning.

Lightning rods are grounded, pointed metallic rods. They prevent charges from building up on surfaces or structures located on the ground. The charges actually "leak" off the points of the lightning rods at such a rapid rate that a build-up of sufficient strength to attract an unlike charge, and therein lightning, becomes impossible.

The important points to remember are that because air is such a good insulator, electrons "climb" up the highest object around in a thunderstorm; moreover, unless that object is a lightning rod, the charge will not leak off quickly enough to avoid attracting attention. Therefore, avoid open flat areas, single trees, hills, water and so forth during a storm. Safe places to be include properly grounded houses, automobiles, and bridges with steel frames. In each of these cases, the structure is a grounded conductor. Also remember that charges tend to accumulate in or on the most pointed portion of a conductor.

Conductors and Insulators

Materials have different abilities to hold their charges. Materials that allow charges to move freely are called conductors. The best conductors are metals, specifically, copper, aluminum, iron and silver.

Materials and substances that hold their charges are good insulators. Electrons do not move freely along insulating materials. Common insulators are glass, hard rubber, dry wood, air and plastic. Even chemically pure water is a good insulator; ordinary water, however, is a good conductor, as is a wet human body.

While there are neither perfect insulators nor perfect conductors, the differences in efficiency of conduction or insulation of certain materials explains why wires of copper or aluminum are used for conducting electricity while plastic or hard rubber coating, glass or plastic supports, and wooden poles are used to insulate wires.

Current (or dynamic) Electricity

Current electricity or current is the flow of electrons in a wire. In order to obtain a flow large enough to be of use, a continuous supply of negative electrons must be maintained at one end of the wire while an excess of positive electrons must be maintained at the other end. Electron current is the term used to describe the electric current that flows from negative to positive while conventional current is the term used to describe the electric current that flows from positive to negative.

The maintenance of a continuous flow of electrons can be achieved in several ways, the two most common of which are using a battery or a generator. In both instances, the process of producing electricity depends upon the transformation of some other form of energy to electrical energy. The battery or chemical cell uses a strip of copper and a strip of zinc in a solution of acid. The zinc slowly dissolves in the chemical reaction that occurs, and the electrons leave the zinc electrode and move to the copper electrode. If a wire is connected from one electrode to another, the electrons will continue to flow through the wire as long as some zinc remains. In this process, chemical energy is converted to electrical energy.

Generators produce most of the energy used in the world. They produce energy by means of a principle called electromagnetic induction. This process occurs when a coil of wire is caused to move in a magnetic field or when a magnet is caused to move inside a coil of wire. The electric current is generated as the magnetic lines of force are cut with a conductor. If the force lines are not cut by moving the magnet, no current results. The faster the magnet is moved, the stronger the magnet, or the more turns in the coil, the greater the current. In the generator, the actual amount of electricity depends both upon the strength of the magnet and the speed at which the coil (or magnet) moves.

Many types of energy are used to turn generators and thus produce electrical energy. Sometimes falling water is used as a form of mechanical energy. In addition, coal, oil, and wood are burned or

nuclear power is used to heat water to steam; in turn, the steam drives the generator. In every instance another form of energy is used to produce electrical energy.

Electric current flows in circuits. A circuit is the path of electron flow, usually from negative to positive charges. This is illustrated in Figure 9.

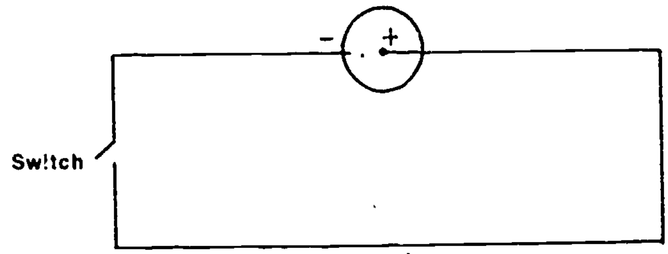


Figure 9: A Dry Cell Circuit

In an electrical circuit created either by a generator or a dry cell, even with a switch open, there is a tendency for electrons to flow. When the switch is closed, the electrons surge through the circuit along the wire. The flow of electrons is called voltage (or electromotive force). The wire through which the electrons flow offers a measurable amount of resistance, with some materials offering mueh more resistance than others. The electrical quantities of resistance, current and voltage are related to each other in a fashion that has been named Ohm's Law. It states that for direct current:

> The current (amperes) in a circuit varies directly as the electromotive force (voltage) and inversely with the resistance (ohms).

Ohm's Law is written as the following formula:

$$I \text{ (amperes)} = \frac{V \text{ (volts)}}{R \text{ (ohms)}}$$

The voltage of a new dry cell is about 1.5 volts; the voltage of an automobile battery is about 12 volts. The voltage of an ordinary house circuit is 110 to 120 volts.

Try your hand at working the following problems.

1. What is the electron current through the cord of a drill that has a resistance of 40 ohms when the drill is plugged into a standard house circuit? Answer: ____________
2. Compute the resistance of a portable welder that draws 50 amperes and is plugged into a 220 volt current. Answer: ____________

Answers: 1 = 3 amperes
2 = 4.4 ohms

There is no circuit that does not offer some resistance. Good conductors such as copper offer less resistance than do poor conductors. Poor conductors are useful to protect against shocks and shorts or in some instances to generate large amounts of heat energy. Resistance not only depends upon the nature of the conductor, but also upon the length and diameter of the conductor and the temperature of the surrounding environment. Resistance varies directly with the length of the conductor and inversely with the diameter of the conductor. That means that the thicker the conductor, the less the resistance, while the longer the conductor, the greater the resistance. In terms of temperature, resistance goes up and down with the temperature. Resistance is much higher at higher temperatures. At very low temperatures, resistance is almost non-existent, and a situation termed superconductivity occurs.

Most circuits have more than one resistance. The wire itself offers one resistance while the tool or motor in use offers another. The wire itself offers little resistance; however, if the tool is a heat tool like a soldering iron or electric welder, the alloy of the tool (or tool wire) offers a much higher resistance. Much more energy is required to move charges through these wires, with the result that more energy is converted to heat.

Heating effects oc :ur with all circuits. The researcher Joule found that if he doubled the amount of current in a circuit, he increased the amount of heat four-fold; if he tripled the amount of current, he increased the heat nine times. This means that the amount of heat produced is in proportion to current squared (I^2). It explains how electric stoves and clothes dryers work, and more importantly, explains the functicn of fuses. A fuse is simply a short piece of wire with a relatively low melting point that is put into a circuit. If a circuit is overloaded and generates too much heat, the fuse metal melts and opens the circuit so that current no longer flows to the items that had been using the electricity. If circuits were not protected by a fuse, the resulting heat could burn or melt away insulation and cause a serious fire. In normal houses, the resistance on a 110–120 volt line should not exceed 1650 watts.

Recall from previous reading that $I = V/R$. A volt represents the transfer of energy per coulomb. A coulomb is a given amount of electrostatic units. To determine voltage, coulombs are divided into joules. Ordinary houses are wired for 110–120 volts. This means that for each coulomb of charge passing in wires, 110–120 joules of work (and 26.3 calories of heat) can be done.

Power itself is measured in watts and is defined as one joule per second. In its simplest form, watts equal voltage times current. This means that if you use a space heater that draws 1000 amperes of current plugged into a regular 110 volt house circuit to warm the area where you are working, you would use 110,000 watt hours or almost 110 kilowatt hours of poer for each hour of heater operation. The watt is the same unit of measure useful for calculating mechanical and heat energy and is equal to work divided by time (in seconds). Remember that 746 watts equal one horsepower.

Additional Information

You may wish to read sections on electricity in texts such as:
H.N. Swenson and J.E. Woods. *Physical Science*. New York: John Wiley & Sons, Inc., 1961.

Self-Test Exercises

Answer the following questions and problems and compare your answers with those in the Appendix. If you answer correctly at least 70% of the items, take the Posttest to this booklet. If you score less than 70%, repeat your work in this chapter.

1. Circle the letter of the following statement that is an incorrect statement of Coulomb's Law.
   a. A shielding medium placed between charges reduces the force of attraction or repulsion.
   b. Unlike charges attract each other while like charges repel each other.
   c. As the distance between charges increases, the force of attraction or repulsion changes proportionally.
   d. The strength of attraction or repulsion is as strong as the product of the charges.

2. Circle the letter of the item that completes the phrase. "Static electricity is usually caused by ______.
   a. friction
   b. gravity
   c. inertia
   d. velocity
3. What are the three characteristics that are typical of places where charges of static electricity accumulate? Answer: ______
4. A material that holds it charge is called a ______.
5. The two most common ways of maintaining a continuous flow of electrons are ______ and ______.
6. What is the number of amperes drawn through a press given 220 volt current and 20 ohms of resistance? Answer: ______
7. How much power in kilowatt hours is being used in a circuit where 110 volts flow and 1650 amperes are generated over an hour of time? Answer: ______

6. Appendix

Answers to Self-Assessment Pretest

1. 120 foot-pounds of work
2. work
3. 1.4 horsepower
4. none
5. 210 feet
6. inertia, gravity, friction
7. multiplies force
8. 200 lbs.
9. 40 grams per cubic centimeter
10. 778 ft.-lbs.
11. convection
12. 77°F
13. 300 ft.-lbs. of heat
14. 40 amperes
15. 2000 watts
16. static and current (or dynamic)
17. an electromagnet and coil
18. they are *like* charges and may both be either positive or negative

Answers to Self-Test Exercises

Chapter 2: Work, Power and Energy

1. They both must be *in the same direction*.
2. 600 foot-pounds
3. (a) 1800 foot-pounds
   (b) .08 horsepower
4. 746 watts of power equal 1 horsepower
5. 4 horsepower
6. Energy can neither be created nor destroyed; it can only be transformed from one form to another with exact equivalence.

Chapter 3: Mechanical Energy and Mechanics

1. B
2. 7:3
3. 150 lbs.
4. speed, direction, and multiply amount of force

5. picture 1: load = blade: fulcrum = rivet: effort = hand hold of handle; picture 2: load = rod going into pump head: fulcrum = arm from lever to right side of pump head; effort = end of handle.
6. 2000 lbs.
7. The weight of the fluid displaced must equal the weight of the object to float.

Chapter 4: Heat Energy

1. a
2. 0°C
3. d
4. 18.3°C
5. It was produced. but inefficient technology did not permit it to be converted entirely to mechanical energy. Therefore. it was dissipated as unuseable.
6. Approximately 11 pounds
7. conduction

Chapter 5: Electrical Energy

1. C
2. a
3. highest points. surfaces. most pointed portion of conductors
4. insulator
5. battery and generator
6. 11 amperes
7. 181.5 kilowatt hours

Posttest

Directions: Answer the following questions drawing upon what you have learned in this booklet. Place your answers in the space provided or on separate work paper. Check your answers with those supplied in this Appendix. Score your test according to the scoring chart on the answer sheet.

1. Circle the letter of the following statement that is *not* an accurate statement of the characteristics of energy.
   a. It cannot be gained or lost. but only transformed with equivalence.
   b. It is the product of force.
   c. It is the capacity to do work.
   d. It can be transformed from one form to another.
2. How much work is done in lifting the 5000 lb. hammer of a pile driver to a height of 40 feet above the pile to be driven? Answer: ____________
3. State briefly. in your own words. the relationship between force and direction when computing work. Answer: ____________
4. Indicate the following equivalent amounts:
   a. 1 horsepower = ____________ watts
   b. 1 horsepower = ____________ foot-pounds per second

5. A caterpillar tractor was used to move 100 tons a distance of 150 feet over a period of 2 hours. How much work was done and at what horsepower? Answers:
   a. ____________________
   b. ____________________
6. A machine operating at 84,000 ft.-lbs. per second is exerting what horsepower? Answer:
   ____
7. Circle the letter of the answer that is the name for the energy of motion.
   a. kinetic energy
   b. potential energy
   c. chemical energy
   d. nuclear energy
8. If it takes twice as far to stop a load weighing 10 as it does a load weighing 5 tons, how much distance is required to stop a 5 ton load traveling at 40 mph as compared to a 5 ton load traveling at 20 mph? Answer: ____________________
9. Mechanical energy is used to work against the forces of friction, gravity and inertia. Match the letter of the resulting change of the body to which mechanical energy is applied in working against the forces of friction, gravity and inertia.

____ inertia	a. heat
____ gravity	b. ~~height~~ or altitude
____ friction	c. speed

10. Simple machines can change force in any of three ways. They are:
    a. ____________________
    b. ____________________
    c. ____________________
11. Every action is always opposed by: (circle the letter of correct answer)
    a. an equal reaction
    b. resulting motion
    c. a change of speed or direction
    d. inertia
12. How much force is required to lift a 750 lb. weight with a lever that has a force arm of 10 ft. and a load arm of 1.5 ft.? Answer: ____________________
13. What is the maximum weight that a person who can exert 200 lbs. of force can move with a 12 ft. lever, given that 1 ft. must always be reserved for the load? Answer:
    ____
14. What is the mechanical advantage gained by using a 20 ft. inclined plance to push a 2 ton weight to the top of a five foot platform? Answswer: ____________________
15. When the principle of conservation is applied to simple machines like pulleys and levers such that force is multiplied, what happens to the distance over which force is applied and to what extent? Answer: ____________________
16. What type of simple machine is a wedge? Answer: ____________________
17. Circle the letter of the statement that is *not* characteristic of pressure for liquids.
    a. It is equal to force per unit area.
    b. It is especially critical for the bottom of the container.
    c. It is derived by pressure = force divided by area.
    d. It is exerted equally in all directions.
18. What is the water pressure for a radiator tank measuring 3 ft. (90 cm) on all sides? Answer: ____________________
19. If a hydraulic jack has a lift platform of 48 sq. ft. and a force plate of 1 sq. ft., how much weight can be lifted using a lift force of 250 lbs.? Answer: ____________________

20. Express 50°C on the Fahrenheit scale. Answer: ____________________
21. Express 90°F on the Celsius or centigrade scale. Answer: ____________________
22. Circle the letter of the type of heat transmission that occurs through the action of currents.
    a. convection
    b. conduction
    c. radiation
23. How many Btu's of heat energy, assuming perfect conversion, are required to transport 3000 lbs. across 100 ft.? Answer: ____________________
24. If you needed to insulate a material, name three insulators you might consider to see if they could be used to do the job.
    Answers: ________________, ________________, and ________________
25. In heat energy terms of both the process and the possible outcome, why must an engine block contain antigreeze to prevent freezing in the winter?
    Answer: outcome—____________________ process—____________________
26. Express 10° Celsius on the Fahrenheit scale. Answer: ____________________
27. Circle the letter of the following statement that is *not* true.
    a. When heat transfer is uninterrupted or unaided, it always proceeds from a warmer body to a cooler body.
    b. By insulating a body, it is possible to slow but not prevent the heat loss process.
    c. When energy is converted from one form to another, the total amount of energy remains the same.
    d. Equal temperatures of different volumes of materials have equal heat.
28. What should you do if you are caught in the open in an electrical thunderstorm?
    Answer: ____
29. Materials that allow electrons to move freely are termed ____________________.
30. Arrange the materials listed below in order of their insulating abilities beginning with the best insulator.
    ____ a. water
    ____ b. air
    ____ c. hard rubber
    ____ d. copper
31. Explain in one sentence the two major ideas that combine to form the statement, "In every instance, another form of energy is used to produce electrical energy." Answer:
    ____
32. Circle the letter of the statement that is *not* true concerning resistance.
    a. Every conductor offers some resistance.
    b. The thicker the conductor, the smaller the resistance.
    c. The longer the conductor, the greater the resistance.
    d. The lower the temperature the smaller the resistance.
    e. The denser the conductor the smaller the resistance.
33. What is the current generated in a circuit that works with 110 volts, has a wire resistance of 3 ohms and a tool resistance of 15 ohms? Answer: ____________________
34. What has happened to a current when a fuse blows out? Answer:
    ____

Answers to Posttest

1. b
1. 200,000 foot-pounds of work
3. They must be in the same direction.
4. a. 746 watts
   b. 550 foot-pounds per second
5. a. 30,000,000 ft.-lbs.
   b. 7.6 horsepower
6. 152.7 horsepower
7. a
8. twice as far
9. inertia = c (speed)
   gravity = b (height or altitude)
   friction = c (heat)
10. change speed, change direction, or change magnitude (multiply force)
11. a
12. at least 112.5 lbs.
13. 2200 lbs.
14. 4:1
15. Distance is increased proportional to the mechanical advantage gained by use of the machine.
16. inclined plane
17. b
18. 90 grams/sq. centimeter
19. 12,000 lbs.
20. 122°F
21. 32°C
22. a
23. 385.6 Btu
24. air, glass, fiberglass, hard rubber, pure water, dry wood
25. outcome: Without antifreeze, the engine could freeze and crack.
    process: Water expands when it freezes.
26. 50°F
27. d
28. lie flat or in a ditch, avoid high spots, single trees and metal objects
29. conductors
30. b, c, a, d
31. So far, static electricity is the only naturally occuring electricity, and it has not been harnessed: the generator and the battery each requires chemical, mechanical, nuclear, or heat energy to drive the machine and produce electricity. (Your answer need not be exactly these words.)
32. e
33. 6.1 amperes
34. The flow in the circuit is interrupted.

Scoring: Each question counts 1 point. You must sco
cessfully. If your score meets or exceeds this minimun
the necessary portions of this booklet.

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